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Constant Pressure Interior Ballistics Code CONPRESS: Theory and User's Manual

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CONPRESS is a constant breech pressure (CBP) interior ballistic code which performs the basic CBP calculation and incorporates optimization and parametric variation algorithms. The derivation of the basic CBP equations and a user's manual for use of the various code options are presented.

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PREFACE

On 30 September 1992, the U.S. Army Ballistic Research Laboratory was deactivated and subsequently became a part of the U.S. Army Research Laboratory (ARL) on 1 October 1992.

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TABLE OF CONTENTS

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LIST OF TABLES

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1. INTRODUCTION

A basic mission of the Advanced Propulsion Technology Branch (APTB), Propulsion and Flight Division (PFD), U.S. Army Research Laboratory (ARL), is the evaluation of novel propulsion concepts and propellant formulations which often involve unusual chemistries. Given the unique nature of many of the proposed propulsion concepts and the lack of detailed information, especially burning rate, associated with many of the candidate propellants, detailed computer simulation is often impossible. However, regardless of the concept, if projectile acceleration is achieved through a gas dynamic (thermodynamic) process, limiting performance estimates can be obtained through the use of a constant breech pressure (CBP) simulation.

CBP simulation is particularly useful in quantifying potential performance of new propellant formulations. As the propellant formulator explores chemistries beyond the traditional single/double/triple base chemistry, impetus as a measure of potential performance for a propellant becomes less reliable. Only a ballistic simulation can account for propellant thermochemical properties (i.e., covolume, ratio-of-specific heats [gamma], etc.) not incorporated in the impetus calculation but which can vary over a much larger range than associated with standard propellant formulations. For example, the value of gamma for traditional solid propellants generally varies between 1.22 and 1.25, yet recently, several propellant formulations have been proposed with gammas in the range of 1.05 to 1.1.

Ballistically, the CBP simulation offers several advantages in evaluating potential gun performance. First, the constant breech pressure gun gives the maximum possible velocity which can be achieved without the use of techniques such as traveling charge to alter down tube pressures. Thus, the calculation provides an absolute measure of maximum velocity performance. Next, for solid propellant simulations, velocity predictions are dependent upon the grain geometry selected for the simulation; assuming a CBP eliminates this variable. Finally, new propulsion concepts often involve liquid, gel (liquid/thickener), emulsified (liquid/liquid), or slurry (solid/liquid) propellants which can be evaluated only by a CBP simulation due to the lack of fixed propellant geometry. In addition, it has been shown (Irish 1985) that well designed solid propellant gun systems achieve velocities between 90% and 95% of the CBP velocity. Table 1 illustrates this fact for a variety of fielded gun systems (Morrison 1990). The ratio of experimental velocity to CBP velocity is termed the "ballistic ratio" (BR).

Table 1. Experimental Velocity and Constant Pressure Velocity for Various Cannons

Gun	Caliber (mm)	Propellant Type	Chamber Vol. (1)	Pmax (MPa)	Vel Exp (m/s)	Vel CP (m/s)	$\frac{V_{exp}}{V_{cp}}$ BR
Bofors L70	40	NC1066	0.55	319	1,005	1,079	0.93
IMI	60	M30	2.33	460	1,620	1,781	0.91
M68	105	M30	6.47	414	1,486	1,620	0.92
M256	120	JA2	9.75	510	1,650	1,740	0.95
XM25	120	JA2	9.75	510	1,739	1,828	0.95
XM25*	120	JA2	10.00	683	2,423	2,490	0.97
Navy 5"/54	127	NACO	13.044	372	808	860	0.94
M198	155	M30A1	18.85	313	826	884	0.93

*High velocity test with 3.02 kg launch mass

The objective of this report is to document the theory and operation of the constant breech pressure computer code CONPRESS. In addition to the standard CBP calculation, CONPRESS incorporates a number of optimization and search algorithms together with extensive parametric variation capabilities. Documentation and use of these options is also provided.

2. THEORY AND DERIVATION OF EQUATIONS

(NOTE: Equivalent derivations have been performed by other researchers over the past 50 years and can be found in various publications.)

α, β, K	Constants
A	Projectile base area
c_p	Heat capacity at constant pressure
c_v	Heat capacity at constant volume
ε	Internal gas energy
F	Force acting on projectile base
γ	Ratio of specific heats

I	Propellant impetus
K_p	Kinetic energy of projectile
K_g	Kinetic energy of gas
M	Molecular weight of gas
m_c	Charge mass
m_p	Projectile mass
η	Propellant covolume
P	Chamber/breech pressure
P_c	Constant breech pressure
$\bar{P}$	Space mean pressure
$\bar{P}_c$	Constant space mean pressure during propellant burning
$\bar{P}_m$	Space mean pressure at projectile exit
P_b	Base pressure
P_{bc}	Constant base pressure during propellant burning
R	Universal gas constant
S	Entropy
T	Gas temperature
T_b	Gas temperature at burnout
T_f	Flame temperature of propellant
U_m	Projectile muzzle velocity
V	Total volume as a function of projectile position
V_b	Gun volume from 0 to x_b, chamber and tube volume to propellant burnout position
V_c	Gun volume from 0 to x_1, chamber volume
V_m	Gun volume from 0 to x_m, chamber and tube volume
V_{bf}	Free gun volume at burnout adjusting for propellant covolume
V_{cf}	Free chamber volume adjusting for propellant covolume
V_{mf}	Free gun volume at projectile muzzle exit adjusting for propellant covolume
x_1	Initial projectile position
x_b	Position of projectile at propellant burnout.
x_m	Projectile position at muzzle exit

For the derivation, the following assumptions are assumed:

(1) The Lagrange gradient adequately describes the pressure and gas velocity profiles of the ballistic cycle. Equations 1–3 summarize the relations due to Lagrange which will be used in the derivation.

$$P = \left(1 + \frac{m_c}{2m_p}\right) P_b , \tag{1}$$

$$\bar{P} = \left(1 + \frac{m_c}{3m_p}\right) P_b , \tag{2}$$

$$K_g = \frac{m_c}{3m_p} K_p . \tag{3}$$

(2) The propellant burns in an ideal manner (i.e., the propellant is instantaneously converted to a gaseous state).

(3) The burn rate of the propellant can be controlled so as to provide a constant chamber pressure till propellant burnout.

(4) The gas is polytropic.

(5) The Nobel-Abel equation of state, Equation 4, is valid.

$$\bar{P}(V - \eta m_c) = m_c \frac{RT}{M} . \tag{4}$$

(6) No energy losses occur during the ballistic cycle.

(7) After burnout, adiabatic expansion of the gas takes place.

(8) The projectile base area equals the cross-sectional area of the tube.

A diagram of the gun with accompanying coordinate system is given in Figure 1. The location, x_1, corresponds to tube entrance, x_b, to the location of the projectile at propellant burnout, and x_m to muzzle exit.

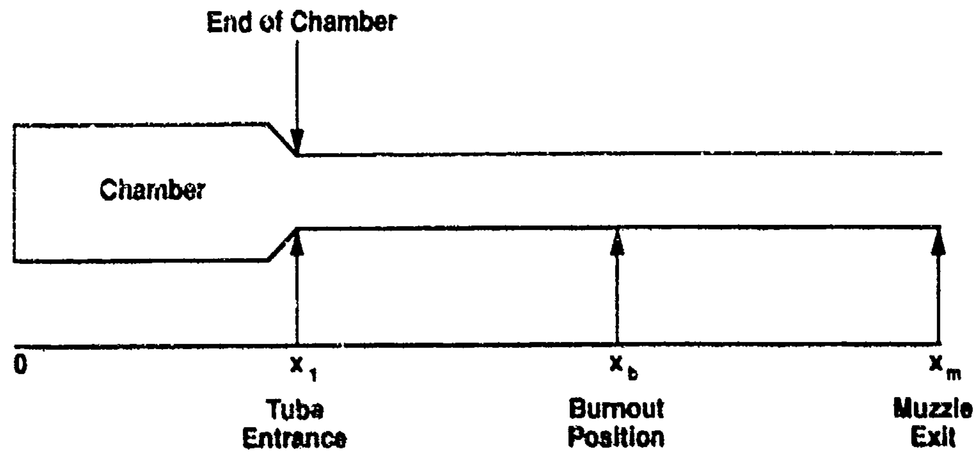

Figure 1. Coordinate system for the gun.

Under the assumption of no energy losses, the kinetic energy of the projectile as it travels from its initial position, x_1, to muzzle exit, x_m, is given by Equation 5.

$$K_p = \int_{x_1}^{x_m} F(x)\,dx\,, \tag{5}$$

where $F(x)$ is the force on the projectile base at position x, $x_1 \leq x \leq x_m$. Note that Equation 5 is not dependent on the CBP assumption but is simply the definition of work. If A is the projectile base area and $P_b(x)$ base pressure at position x, $x_1 \leq x \leq x_m$, then

$$F(x) = AP_b(x)\quad . \tag{6}$$

Also, from the assumption that the projectile base area is equal to the cross-sectional area of the tube,

$$V(x) = A(x - x_1) + V_c \Rightarrow dV = A\,dx \quad , \tag{7}$$

where $V(x)$ is the total volume of chamber plus gun tube to location x, $x_1 \leq x \leq x_m$. Substitution of Equations 6 and 7 into Equation 5 yields

$$K_p = \int_{x_1}^{x_m} A P_b(x)\,dx = \int_{V_c}^{V_m} P_b(V)\,dV \quad , \tag{8}$$

where $V_c = V(x_1)$ and $V_m = V(x_m)$.

If burnout occurs at or after muzzle exit, then the integral in Equation 8 can easily be evaluated if a CBP is assumed since by the Lagrange assumption, Equation 1, the base pressure also remains constant. This gives

$$K_p = P_{bc} A(x_m - x_1) \, , \tag{9}$$

or, using Equation 1 to transform from base to breech pressure, the kinetic energy of the projectile would be given by Equation 10,

$$K_p = A(x_m - x_1) \frac{P_c}{1 + \dfrac{m_c}{2m_p}} \, . \tag{10}$$

However, if burnout occurs before muzzle exit, the base pressure will have a profile as shown in Figure 2, and the energy imparted to the projectile during the expansion phase, from x_b to x_m, must also be calculated. From the assumptions, it is assumed that the expansion will be adiabatic. Thus, the work performed on the projectile by the expanding gas is a function of space mean pressure instead of base or chamber pressure. Thus, Equation 8, which gives the total kinetic energy of the projectile in terms of base pressure, must be rewritten in terms of space means pressure. To perform this transformation, consider multiplying both sides of Equation 8 by the factor $(1 + m_c/3m_p)$.

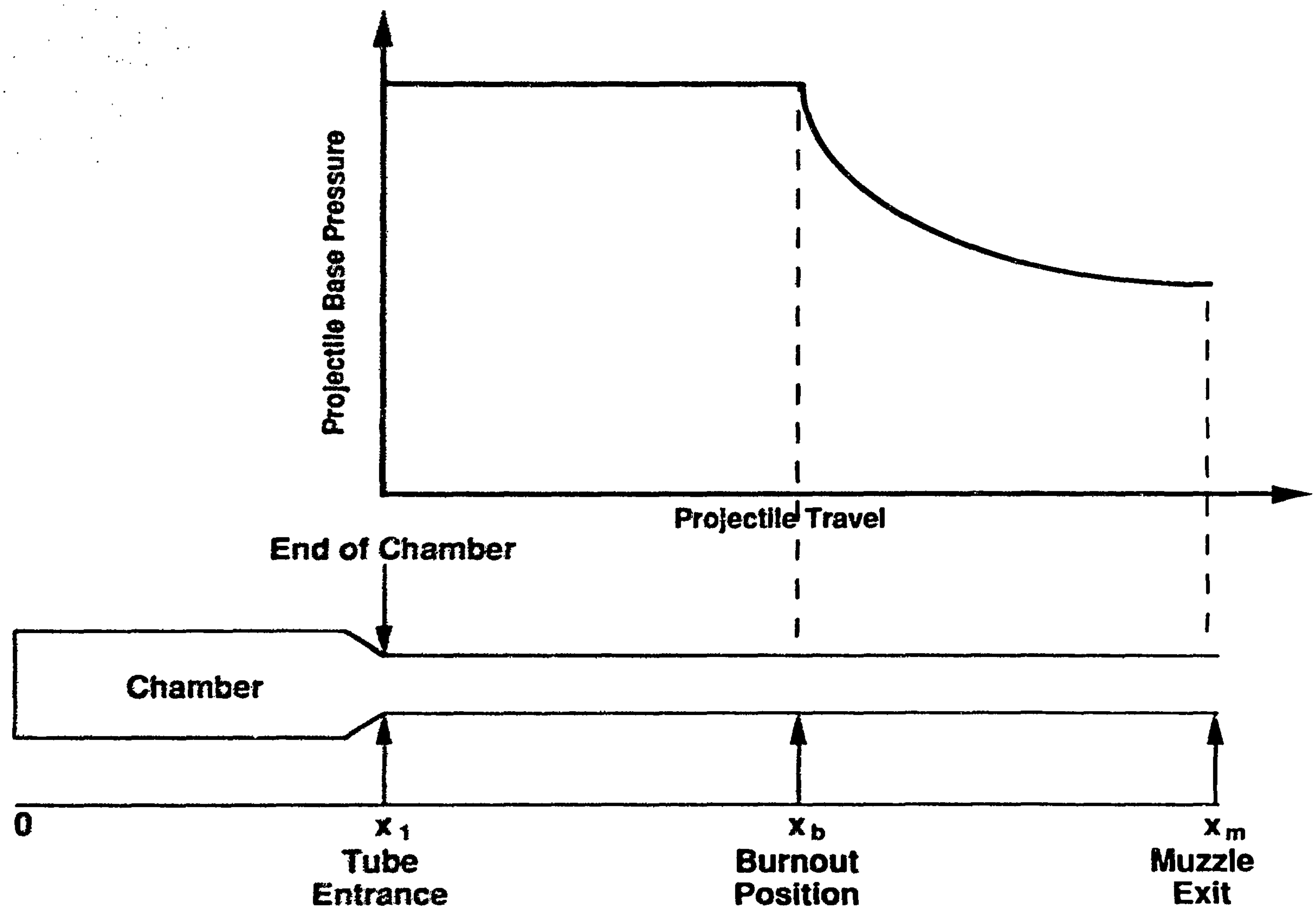

Figure 2. Typical projectile base pressure vs. projectile travel if propellant burnout occurs prior to muzzle exit.

$$\left(1 + \frac{m_c}{3m_p}\right)K_p = \left(1 + \frac{m_c}{3m_p}\right)\int_{V_c}^{V_m} P_b(V)\,dV\,. \tag{11}$$

Using Equation 2 yields.

$$\left(1 + \frac{m_c}{3m_p}\right)K_p = \int_{V_c}^{V_m} \bar{P}(V)\,dV\,. \tag{12}$$

It is of interest to note that the integral on the right-hand side of Equation 12 represents the total usable work which can be extracted from the propellant, while the left-hand side is the sum of the kinetic energy of the projectile and the kinetic energy of the gas using the Lagrange assumption given by Equation 3 to relate the kinetic energy of the gas and projectile.

From this point forward, a constant breech pressure during propellant burning is assumed. Equation 12 provides a means for determining K_p by evaluating the integral on the right-hand side of the equation. While the propellant burns, by the Lagrange assumption, the chamber, space mean, and base pressures remain constant. Letting $\bar{P}_c$ be the constant space mean during the time the propellant burns, Equation 12 can be rewritten in the following manner:

$$\left(1 + \frac{m_c}{3m_p}\right)K_p = \int_{V_c}^{V_b} \bar{P}_c(V)\,dV + \int_{V_b}^{V_m} \bar{P}(V)\,dv\,. \tag{13}$$

Evaluating the first integral gives

$$\left(1 + \frac{m_c}{3m_p}\right)K_p = \bar{P}_c(V_b - V_c) + \int_{V_b}^{V_m} \bar{P}(V)\,dV\,. \tag{14}$$

To evaluate the second integral, $\bar{P}(V)$ must be replaced with an expression involving V as the variable.

For a polytropic gas (Whitman 1974) during the expansion phase,

$$\bar{P}(V-\eta m_c)^{\gamma} = \alpha e^{\frac{S}{c_v}}, \tag{15}$$

where γ is the specific heat ratio, η the propellant covolume, S the entropy, c_v the value of specific heat at constant volume, and α a constant. Also, for an adiabatic gas, entropy is constant. Thus, assuming c_v remains constant, Equation 15 becomes

$$\bar{P}(V - \eta m_c)^{\gamma} = K, \tag{16}$$

where K is a constant.

Solving for $\bar{P}$ yields

$$\bar{P} = \frac{K}{(V-\eta m_c)^{\gamma}}. \tag{17}$$

Substituting Equation 17 into Equation 14,

$$\left(1 + \frac{m_c}{3m_p}\right)K_p = \bar{P}_c(V_b-V_c) + \int_{V_b}^{V_m} \frac{K}{(V-\eta m_c)^{\gamma}}\,dV. \tag{18}$$

Integrating,

$$\left(1 + \frac{m_c}{3m_p}\right)K_p = \bar{P}_c(V_b - V_c) - \frac{K}{(\gamma-1)(V-\eta m_c)^{\gamma-1}}\Big|_{V_b}^{V_m}, \tag{19}$$

or

$$\left(1 + \frac{m_c}{3m_p}\right)K_p = \bar{P}_c(V_b - V_c) + \frac{K}{(\gamma-1)(V_b-\eta m_c)^{\gamma-1}} - \frac{K}{(\gamma-1)(V_m-\eta m_c)^{\gamma-1}}. \tag{20}$$

To simplify Equation 20, the last two terms can be rewritten to give

$$\left(1+\frac{m_c}{3m_p}\right) K_p = \bar{P}_c\,(V_b - V_c) + \frac{K(V_b - \eta m_c)}{(\gamma-1)(V_b-\eta m_c)^{\gamma}} - \frac{K(V_m - \eta m_c)}{(\gamma-1)(V_m-\eta m_c)^{\gamma}}\,, \tag{21}$$

which upon substitution of Equation 17 gives Equation 22,

$$\left(1+\frac{m_c}{3m_p}\right) K_p = \bar{P}_c(V_b - V_c) + \frac{\bar{P}_c(V_b-\eta m_c) - \bar{P}_m(V_m - \eta m_c)}{\gamma-1}\,. \tag{22}$$

By assumption, the constant chamber pressure during propellant burning is known and thus $\bar{P}_c$ is also known by the Lagrange assumptions. The geometry of the gun fixes V_c and V_m. Finally, covolume, η, gamma, γ, and propellant mass, m_c, are known properties of the propellant, and, hence, the only unknown quantities in Equation 22 are K_p, V_b, and $\bar{P}_m$. To eliminate $\bar{P}_m$, apply Equation 16 at the beginning and end of the expansion phase. This gives

$$\bar{P}_m(V_m - \eta m_c)^{\gamma} = K = \bar{P}_c(V_b - \eta m_c)^{\gamma}\,, \tag{23}$$

or

$$\bar{P}_m = \bar{P}_c\left(\frac{V_b - \eta m_c}{V_m - \eta m_c}\right)^{\gamma}. \tag{24}$$

Substitution of Equation 24 into Equation 22 yields

$$\left(1+\frac{m_c}{3m_p}\right) K_p = \bar{P}_c(V_b - V_c) + \frac{\bar{P}_c(V_b - \eta m_c)}{\gamma-1} - \frac{\bar{P}_c}{\gamma-1}(V_m - \eta m_c)\left(\frac{V_b - \eta m_c}{V_m - \eta m_c}\right)^{\gamma}. \tag{25}$$

Now,

$$(V_b - V_c) = (V_b - \eta m_c - [V_c - \eta m_c]) . \tag{26}$$

For convenience, let the free volumes be given by

$$V_{cf} = V_c - \eta m_c , \tag{27}$$

$$V_{bf} = V_b - \eta m_c , \tag{28}$$

and

$$V_{mf} = V_m - \eta m_c . \tag{29}$$

Finally, solving Equations 1 and 2 for space mean pressure in terms of chamber pressure, and applying the result to the known constant chamber pressure, produces Equation 30,

$$\bar{P}_c = \frac{\left(1 + \frac{m_c}{3m_p}\right)}{\left(1 + \frac{m_c}{2m_p}\right)} P_c . \tag{30}$$

Substituting Equations 26–30 into Equation 25,

$$\left(1 + \frac{m_c}{3m_p}\right) K_p = \frac{\left(1 + \frac{m_c}{3m_p}\right)}{\left(1 + \frac{m_c}{2m_p}\right)} P_c \left(V_{bf} - V_{cf} + \frac{V_{bf}}{\gamma - 1} - \frac{V_{mf}}{\gamma - 1}\left(\frac{V_{bf}}{V_{mf}}\right)^{\gamma}\right), \tag{31}$$

which upon simplifying, gives an expressing for K_p in Equation 32.

$$K_p = \frac{P_c}{1 + \frac{m_c}{2m_p}} \left(\frac{\gamma}{\gamma - 1} V_{bf} - V_{cf} - \frac{V_{mf}}{\gamma - 1} \left(\frac{V_{bf}}{V_{mf}} \right)^{\gamma} \right). \tag{32}$$

Before determining an expression for V_{bf}, the consistency of the equations can be checked by assuming burnout at muzzle exit (i.e., $V_{bf} = V_{mf}$ in Equation 32). This should reduce Equation 32 to Equation 10. Letting $V_{bf} = V_{mf}$ in Equation 32 yields

$$K_p = \frac{P_c}{1 + \frac{m_c}{2m_p}} \left(\frac{\gamma}{\gamma - 1} V_{mf} - V_{cf} - \frac{V_{mf}}{\gamma - 1} \left(\frac{V_{mf}}{V_{mf}} \right)^{\gamma} \right). \tag{33}$$

Simplifying, Equation 10 is obtained:

$$K_p = \frac{P_c}{1 + \frac{m_c}{2m_p}} (V_{mf} - V_{cf}) = \frac{P_c}{1 + \frac{m_c}{2m_p}} A(x_m - x_1) . \tag{34}$$

To obtain an expression for V_{bf}, the Nobel-Abel equation of state, Equation 4, together with energy conservation during the time which the propellant is burning, will be utilized. At burnout, the Nobel-Abel equation of state becomes

$$\bar{P}_c V_{bf} = m_c \frac{RT_b}{M} . \tag{35}$$

Note that the unknown gas temperature, T_b, has been introduced and needs to be eliminated. Now, while the propellant burns, since no energy loss is assumed, the change in the internal gas energy must translate into the work being performed on the projectile and propelling gas. The change in internal energy of a gas per unit mass is given by Equation 36 (Whitman 1974).

$$\varepsilon = c_v dT . \tag{36}$$

Thus, the total change in internal energy during propellant burning, assuming a constant c_v, is

$$m_c \varepsilon = m_c c_v dT = m_c c_v (T_f - T_b) . \tag{37}$$

Now the work done on the gas and projectile during the burning of the propellant is

$$\bar{P}_c (V_b - V_c) = \bar{P}_c (V_b - \eta m_c - [V_1 - \eta m_c]) = \bar{P}_c (V_{bf} - V_{cf}) . \tag{38}$$

Equating the expressions for work in Equation 37 and 38 gives

$$\bar{P}_c (V_{bf} - V_{cf}) = m_c c_v (T_f - T_b) . \tag{39}$$

Equations 35 and 39 provide a system of two equations in two unknowns, V_{bf} and T_b, which can be solved for V_{bf}, as given in Equation 40.

$$V_{bf} = \frac{m_c^2 c_v \frac{T_f R}{M} + m_c \frac{R}{M} \bar{P}_c V_{cf}}{\bar{P}_c m_c (c_v + \frac{R}{M})} . \tag{40}$$

By definition, propellant impetus or force, I, is given by

$$I = \frac{R T_f}{M} . \tag{41}$$

and

$$\frac{R}{M} = c_p - c_v . \tag{42}$$

Substituting Equations 41 and 42 into Equation 40 and simplifying,

$$V_{bf} = \frac{m_c c_v I}{\bar{P}_c c_p} + \frac{(c_p - c_v) V_{cf}}{c_p} , \tag{43}$$

or

$$V_{bf} = \frac{m_c I}{\bar{P}_c \gamma} + \frac{\gamma - 1}{\gamma} V_{cf} . \tag{44}$$

Making use of Equation 30 to eliminate $\bar{P}_c$, the final equation for V_{bf} is obtained:

$$V_{bf} = \frac{m_c I \left(1 + \frac{m_c}{2 m_p}\right)}{\gamma \left(1 + \frac{m_c}{3 m_p}\right) P_c} + \frac{\gamma - 1}{\gamma} V_{cf} . \tag{45}$$

Equation 32 together with Equation 45 provides an expression for K_p in terms of P_c, m_c, m_p, γ, I, V_{cf}, and V_{mf}. However, V_{cf} and V_{mf} can both be expressed in terms of V_c and are given in Equation 46 and 47:

$$V_{cf} = V_c - \eta m_c ; \tag{46}$$

$$V_{mf} = V_c + (A (x_m - x_1) - \eta m_c). \tag{47}$$

Thus, Equations 32 and 45–47 provide a means to compute K_p in terms of the known quantities P_c, m_c, m_p, γ, I, A, V_c, η, and $(x_m - x_1)$, the projectile travel. The muzzle velocity can then be computed using

$$Vel_m = \sqrt{2\frac{K_p}{m_p}}\,. \tag{48}$$

It is also of interest to know the location of the projectile at propellant burnout. From Equation 28,

$$V_{bf} = V_b - \eta\, m_c = V_c + A(x_b - x_1) - \eta\, m_c\,. \tag{49}$$

Substituting in Equation 45 and solving for $(x_b - x_1)$,

$$x_b - x_1 = \frac{m_c\, l\left(1 + \dfrac{m_c}{2\, m_p}\right)}{\gamma\left(1 + \dfrac{m_c}{3\, m_p}\right) P_c A} + \frac{\gamma - 1}{\gamma A} V_{cf} + \frac{\eta m_c}{A} - \frac{V_c}{A}\,. \tag{50}$$

Equation 50 can be used to determine the projectile position at propellant burn-out relative to the initial position of the projectile.

3. PROGRAM OPTIONS, REQUIRED INFORMATION, AND INPUT DATA DECK STRUCTURE

The equations derived in the previous section together with optimization algorithms have been coded in FORTRAN to produce the computer code CONPRESS (Appendix A). Seven different computational options, described in Table 2, are available in CONPRESS Table 3 summarizes the required input information for each option. For option 6 the required input is determined by the option (1–5) selected for the parametric study.

Table 2. Computational Options for CONPRESS

Computational	Description
1	Compute muzzle velocity given chamber volume and charge mass.
2	Compute required charge mass given chamber volume, desired velocity, and maximum loading density.
3	Compute required charge mass and chamber volume given desired velocity and loading density.
4	Compute the charge mass to produce optimal muzzle velocity given the chamber volume and maximum loading density.
5	Compute the charge mass and chamber volume to produce optimal muzzle velocity given loading density.
6	Performs a parametric study over a specified range of one or more of the input variables, the study can be performed for any of the options 1-5.
7	Option to end program.

Table 3. Required Input Data for Computational Options 1-5

Input Variable	Units	Computational Option				
		1	2	3	4	5
Maximum Breech Pressure	MPa	•	•	•	•	•
Charge Mass	kg	•				
Projectile Mass	kg	•	•	•	•	•
Gamma	(-)	•	•	•	•	•
Covolume	cm^3/g	•	•	•	•	•
Impetus	J/g	•	•	•	•	•
Propellant Density	g/cm^3	•	•	•	•	•
Chamber Volume	l (liters)	•	•		•	
Bore Diameter	mm	•	•	•	•	•
Projectile Travel	cm	•	•	•	•	•
Desired Velocity	m/s		•	•		
Loading Density	g/cm^3		•	•	•	•

The structure of the input deck for CONPRESS for single and multiple runs is given in Table 4. [Note: The commas utilized in Table 4 to separate entries on the same line are not required in an actual input deck, a space should separate the entries.] It should also be noted that all data items must be assigned a value even if that parameter is not used in the computation. For example, option 1 does not require input of the loading density since both the charge mass and chamber volume are input values. However, a value must be entered in the input deck for the loading density. This value will be ignored in the computation. In the following sections additional information about specifics of the input deck for each option will be discussed.

As indicated in Table 4, if multiple runs are to be performed, an output file name is not repeated for each run. All output is written to the same file. Note also that to terminate the program, a 7 should be entered after the last data deck, no title is needed.

Table 4. Structure of Input Deck for CONPRESS

	Single Run
Line 1:	Output file name
Line 2:	Title
Line 3:	Run Option (see Table 2)
Line 4:	Maximum Breech Pressure (Constant Breech Pressure Value)
Line 5:	Charge Mass, Projectile Mass
Line 6:	Gamma, Covolume, Impetus, Propellant Density
Line 7:	Chamber Volume, Bore Diameter, Projectile Travel
Line 8:	Desired Velocity, Loading Density
Line 9:	7 (to indicate end of run, program will correctly terminate if this line is not included.
	Multiple Runs
Line 1:	Output file name
Line 2:	Title Run 1
Line 3:	Run Option (see Table 2)
Line 4:	Maximum Breech Pressure (Constant Breech Pressure Value)
Line 5:	Charge Mass, Projectile Mass
Line 6:	Gamma, Covolume, Impetus, Propellant Density
Line 7:	Chamber Volume, Bore Diameter, Projectile Travel
Line 8:	Desired Velocity, Loading Density
Line 9:	Title Run 2
Line 10:	Run Option (see Table 2)
Line 11:	Maximum Breech Pressure (Constant Breech Pressure Value)
Line 12:	Charge Mass, Projectile Mass
Line 13:	Gamma, Covolume, Impetus, Propellant Density
Line 14:	Chamber Volume, Bore Diameter, Projectile Travel
Line 15:	Desired Velocity, Loading Density
	Lines 9-15 are repeated for each subsequent run
Line N:	7 (to indicate end of run, program will correctly terminate if this line is not included).

TEST CASE 1: Computational Option 1

Option 1 is a direct application of the equations to predict projectile velocity, kinetic energy and projectile position at propellant burnout. Both entries on line 8 (desired velocity and loading density) of the input file are not utilized in the computation. However, as mentioned in the previous section, values for each must be provided. Table 5 provides a sample input deck for option 1, the corresponding output for the CONPRESS run is given in Table 6.

Table 5. CONPRESS Input Deck for Option 1

```
cpv21.ot1
This tests option 1 for latest version of CONPRESS.
1
575.
9. 9.
1.225 .996 1140. 1.58
10.5 120. 475.
1200. .95
7
```

To verify the coding the interior ballistic code, IBHVG2 (Anderson and Fickie 1987) was run with the same input parameters (Table 5) using the constant breech pressure mode with a Lagrange gradient. Pertinent results of the IBHVG2 run are given in Table 7. As can be seen from a comparison of Tables 6 and 7 results are virtually identical.

TEST CASE 2: Computational Option 2

In option 2, the charge mass required to obtained the desired velocity entered on line 8 of the input deck is the quantity sought. Thus, all input values except for the charge mass entered on line 5 are utilized. A simple bisection method for root finding is employed to obtain the desired charge mass. The function used is the difference between the predicted velocity and the desired velocity as a function of charge mass. The initial interval for the charge mass over which the search will be performed is that obtained by assuming that the desired velocity will occur for a charge mass between 10% and 100% of

Table 6. CONPRESS Output for Input Deck of Table 5

INPUT PARAMETERS

Input File: cpv21.op1	Output File: cpv21.ot1
Run Option: 1	
<u>Gun Parameters</u>	<u>Propellant Parameters</u>
Cham. Vol. (L): 10.5000	Impetus (J/g): 1,140.00
Tube Diam. (mm): 120.0000	Gamma (-): 1.22500
Proj. Trav. (cm): 475.0000	Covolume (cm^3/g): .99600
Proj. Mass (kg): 9.00000	Density (g/cm^3): 1.58000
Max Press. (MPa): 575.0000	Input Prop. (kg): 9.00000
Target Vel. (m/s): 1,200.0000	Target LD (g/cm^3): .95000

RESULTS

<u>Ballistic Values</u>	<u>Energy Information</u>
Velocity (m/s): 1,667.5470	Prop. Energy (MJ): 45.59999
Burnout (cm): 133.8050	Proj. KE (MJ): 12.51320 (27.4%)
Cham. Vol. (L): 10.50000	Gas KE (MJ): 4.17107 (9.1%)
Prop. Mass (kg): 9.00000	Gas Internal (MJ): 28.91572 (63.4%)
Prop. LD (g/cm^3): 0.85714	
Expansion Ratio (-): 6.11631	
Muzzle Exit Press (MPa): 88.31	
Mass Charge/Mass Proj (c/m ratio): 1.00000	
Piezometric Efficiency: 0.405	

Table 7. Results From IBHVG2 Run With Identical Inputs for Constant Pressure Calculations

<u>Ballistic Values</u>	<u>Energy Information</u>
Velocity (m/s): 1,667.67	Prop. Energy (MJ): 45.6
Burnout (cm): 133.8	Proj. KE (MJ): 12.515120 (27.45%)
	Gas KE (MJ): 4.171707 (9.15%)
	Gas Internal (MJ): 28.907010 (63.9%)
Prop. LD (g/cm^3): 0.857143	
Expansion Ratio (-): 6.116	
Muzzle Exit Press (MPa): 88.2791	
Mass Charge/Mass Proj (c/m ratio): 1.00000	
Piezometric Efficiency: 0.405	

the maximum charge mass which can be placed in the chamber. This maximum charge mass is obtained by multiplying chamber volume (first entry line 7) by loading density (second entry line 8). Unfortunately, this choice for the initial charge mass interval may result in a situation where the charge masses associated with endpoints do not produce a sign change in the function as required by the bisection method. In this case, the user is warned of the difficulty and is prompted for a new interval on which the search is to be performed. This condition will most often occur when the desired velocity is close to the optimal velocity. One method to alleviate this problem is to first run Option 4 to determine the charge mass for optimal velocity, and then use this value as the right-hand endpoint of search interval when prompted by the program.

To validate the search algorithm, IBHVG2 was run in the constant pressure mode with a charge mass of 7 kg. All other input remained the same as used in the test case for Option 1. The calculated IBHVG2 velocity was 1,549.07 m/s which was then entered as the desired velocity for the CONPRESS calculation. The CONPRESS input deck is given in Table 8 with the results in Table 9. [Note: A run time error occurring during the execution of the program indicates that the desired velocity cannot be obtained within the design parameters (projectile mass, bore diameter, projectile travel, chamber volume, propellant properties, and maximum pressure) specified.]

Table 8. CONPRESS Input Deck for Option 2

```
cpv21.ot2
This will validate option 2 of latest version of CONPRESS.
2
575.
1. 9.
1.225 .996 1140. 1.58
10.5 120. 475.
1549.07 .95
7
```

As can be seen in Table 9, CONPRESS computed a charge mass of 7.00109 kg to obtain the desired velocity of 1,549.07 m/s. This represents a 0.015% difference with the IBHVG2 value of 7 kg. Thus, Option 2 appears to correctly determine the desired charge mass.

Table 9. CONPRESS Output for Input Deck of Table 8

INPUT PARAMETERS

Input File: cpv21.op2
Run Option: 2

Output File: cpv21.ot2

Gun Parameters	Propellant Parameters
Cham. Vol. (L): 10.5000	Impetus (J/g): 1,140.00
Tube Diam. (mm): 120.0000	Gamma (-): 1.22500
Proj. Trav. (cm): 475.0000	Covolume (cm^3/g): 0.99600
Proj. Mass (kg): 9.00000	Density (g/cm^3): 1.58000
Max Press. (MPa): 575.0000	Input Prop. (kg): 1.00000
Target Vel. (m/s): 1,549.0700	Target LD (g/cm^3): 0.95000

RESULTS

Ballistic Values	Energy Information
Velocity (m/s): 1,549.0700	Prop. Energy (MJ): 35.47216
Burnout (cm): 85.0453	Proj. KE (MJ): 10.79828 (30.4%)
Cham. Vol. (L): 10.50000	Gas KE (MJ): 2.79999 (7.9%)
Prop. Mass (kg): 7.00109	Gas Internal (MJ): 21.87390 (61.7%)
Prop. LD (g/cm^3): 0.66677	
Expansion Ratio (-): 6.11631	
Muzzle Exit Press (MPa): 68.27	
Mass Charge/Mass Proj (c/m ratio): 0.77790	
Piezometric Efficiency: 0.350	

TEST CASE 3: Computational Option 3

This option is similar to Option 2 except that the chamber volume is also a variable. The calculation will determine both the charge mass and minimal chamber volume (i.e., smallest chamber volume which will hold the charge mass, charge mass divided by loading density) required to obtain the desired velocity. As in Option 2, a bisection method is utilized to obtain the desired charge mass. The input charge mass, line 5, is taken as the left-hand endpoint for the initial search interval. The right-hand endpoint is obtained by increasing the input charge mass by successive multiplications of a factor of 1.2 until a suitable value for the bisection method is determined. The chamber volume entered on line 7 is not utilized in the computation. [Note: As with Option 2, a run time error occurring during the execution of the program indicates that the desired velocity cannot be obtained within the design parameters (projectile mass, bore diameter, projectile travel, propellant properties, and maximum pressure) specified.]

Input and output for Option 3 are given in Tables 10 and 11. From Table 11 the desired velocity of 1,500 m/s is obtained using 5.39472 kg of propellant with a chamber volume of 5.67865 l. Running CONPRESS with Option 1 with these values for charge mass and chamber volume yields a velocity of 1,500 m/s, thus validating the algorithm for Option 3.

Table 10. CONPRESS Input Deck for Option 3

```
cpv21.ot3
This is the test of option 3 of latest version of CONPRESS.
3
575.
1. 9.
1.225 .996 1140. 1.58
10.5 120. 475.
1500 .95
7
```

TEST CASE 4: Computational Option 4

Option 4 involves the determination of charge mass which will result in optimal muzzle velocity given all other input parameters fixed. This is a standard mathematical optimization problem (i.e., optimize a function, velocity, of a single independent variable, charge mass). Traditionally two approaches are available to perform an optimization of a function of a single variable. One involves the computation of the derivative while the second does not. For CONPRESS, the former approach has been rejected due to the complexity of taking the derivative of the energy equation (Equation 32). Instead, an inverse parabolic interpolation method is employed in searching for the extrema. Specifically, the method utilized in the program is a method due to Brent (1973).

In the input deck, both the charge mass, line 5, and the desired velocity, line 8, are ignored. The interval for the charge mass over which the search will be conducted runs from 0 kg to the maximum mass of propellant which can be loaded into the chamber, chamber volume multiplied by loading density.

A sample input deck and resulting CONPRESS output are shown in Tables 12 and 13.

Table 11. CONPRESS Output for Input Deck of Table 10

INPUT PARAMETERS

Input File: cpv21.op3	Output File: cpv21.ot3
Run Option: 3	
<u>Gun Parameters</u>	<u>Propellant Parameters</u>
Cham. Vol. (L): 10.5000	Impetus (J/g): 1,140.00
Tube Diam. (mm): 120.0000	Gamma (-): 1.22500
Proj. Trav. (cm): 475.0000	Covolume (cm^3/g): 0.99600
Proj. Mass (kg): 9.00000	Density (g/cm^3): 1.58000
Max Press. (MPa): 575.0000	Input Prop. (kg): 1.00000
Target Vel. (m/s): 1,500.0000	Target LD (g/cm^3): 0.95000

RESULTS

<u>Ballistic Values</u>	<u>Energy Information</u>
Velocity (m/s): 1,500.0000	Prop. Energy (MJ): 27.33324
Burnout (cm): 81.4230	Proj. KE (MJ): 10.12500 (37.0%)
Cham. Vol. (L): 5.67865	Gas KE (MJ): 2.02302 (7.4%)
Prop. Mass (kg): 5.39472	Gas Internal (MJ): 15.18522 (55.6%)
Prop. LD (g/cm^3): 0.95000	
Expansion Ratio (-): 10.46021	
Muzzle Exit Press (MPa): 52.71	
Mass Charge/Mass Proj (c/m ratio): 0.59941	
Piezometric Efficiency: 0.328	

Table 12. CONPRESS Input Deck for Option 4

```
cpv21.ot4
This is a test of option 4 of the latest version of CONPRESS.
4
575.
1. 9.
1.225 .996 1140. 1.58
10.5 120. 475
1500 .95
7
```

Table 13. CONPRESS Output for Input Deck of Table 12

INPUT PARAMETERS	
Input File: cpv21.op4	Output File: cpv21.ot4
Run Option: 4	
Gun Parameters	Propellant Parameters
Cham. Vol. (L): 10.5000	Impetus (J/g): 1,140.00
Tube Diam. (mm): 120.0000	Gamma (-): 1.22500
Proj. Trav. (cm): 475.0000	Covolume (cm^3/g): 0.99600
Proj. Mass (kg): 9.00000	Density (g/cm^3): 1.58000
Max Press. (MPa): 575.0000	Input Prop. (kg): 1.00000
Target Vel. (m/s): 1,500.0000	Target LD (g/cm^3): 0.95000
RESULTS	
Ballistic Values	Energy Information
Velocity (m/s): 1,709.2450	Prop. Energy (MJ): 50.53999
Burnout (cm): 157.9224	Proj. KE (MJ): 13.14683 (26.0%)
Cham. Vol. (L): 10.50000	Gas KE (MJ): 4.85702 (9.6%)
Prop. Mass (kg): 9.97500	Gas Internal (MJ): 32.53614 (64.4%)
Prop. LD (g/cm^3): 0.95000	
Expansion Ratio (-): 6.11631	
Muzzle Exit Press (MPa): 98.47	
Mass Charge/Mass Proj (c/m ratio): 1.10833	
Piezometric Efficiency: 0.426	

For a chamber volume of 10.5 and a loading density of 0.95 g/cm^3, successive runs of CONPRESS utilizing Option 1 indicates that the maximum velocity will occur when the chamber is totally filled with propellant. This corresponds to 9.975 kg of propellant (10.5 * .95) which is obtained by CONPRESS using Option 4 (see Table 13). Thus, the algorithm for Option 4 appears to be functioning correctly.

TEST CASE 5: Computational Option 5

This option is similar to Option 4 except that the chamber volume is taken to be the minimal volume to accommodate the charge mass. The chamber volume is computed as described in Option 3. All comments concerning Option 4 apply in this option with the exception of the chamber volume in line 7. For Option 5, the chamber volume, entered on line 7, represents the maximum acceptable chamber volume and is utilized in determining the maximum charge mass considered in the search.

Sample input and output for Option 5 are provided in Tables 14 and 15.

Table 14. CONPRESS Input Deck for Options 5 and 6

```
cpv21.ot5
Test of the output routines and option 5
5
575.
1. 9.
1.225 .996 1140. 1.58
25. 120. 475.
1500 .95
7
```

Table 15. CONPRESS Output for Input Deck of Table 14

INPUT PARAMETERS

Input File: cpv21.op5
Run Option: 5

Output File: cpv21.ot5

Gun Parameters

Cham. Vol. (L): 25.0000
Tube Diam. (mm): 120.0000
Proj. Trav. (cm): 475.0000
Proj. Mass (kg): 9.00000
Max Press. (MPa): 575.0000
Target Vel. (m/s): 1,500.0000

Propellant Parameters

Impetus (J/g): 1,140.00
Gamma (-): 1.22500
Covolume (cm^3/g): 0.99600
Density (g/cm^3): 1.58000
Input Prop. (kg): 1.00000
Target LD (g/cm^3): 0.95000

RESULTS

Ballistic Values

Velocity (m/s): 1,773.6740
Burnout (cm): 264.2473
Cham. Vol. (L): 16.79735
Prop. Mass (kg): 15.95750
Prop. LD (g/cm^3): 0.95000
Expansion Ratio (-): 4.19820
Muzzle Exit Press (MPa): 151.01
Mass Charge/Mass Proj (c/m ratio): 1.77306
Piezometric Efficiency: 0.458

Energy Information

Prop. Energy (MJ): 80.85132
Proj. KE (MJ): 14.15664 (17.5%)
Gas KE (MJ): 8.36683 (10.3%)
Gas Internal (MJ): 58.32785 (72.1%)

To validate the search algorithm, partial results from a parametric run of CONPRESS (Option 6) in which the charge mass and chamber volume were varied are given in Table 16; the input deck is shown in Table 17. As can be seen from a comparison of Tables 15 and 16, the correct maximum velocity was obtained utilizing Option 5.

TEST CASE 6: Multiple Runs

This test case is provide to illustrate the structure of the input deck for multiple runs of CONPRESS. An input deck for two runs is given in Table 18 with the corresponding output in Table 19 (compare to Tables 6 and 9).

Table 16. Partial CONPRESS Results of a Parametric Run to Determine Optimal Velocity

Maximum Pressure (MPa)	Prop. Mass (kg)	Cham. Vol. (liters)	Load. Den. (g/cm^3)	Velocity (m/s)	Burnout (cm)
575.0000	15.8000	16.7000	0.9461	1,773.1320	260.8842
575.0000	15.8000	16.8000	0.9405	1,772.3870	260.1642
575.0000	15.8000	16.9000	0.9349	1,771.6400	259.4406
575.0000	15.8500	16.7000	0.9491	1,773.5420	262.1747
575.0000	15.8500	16.8000	0.9435	1,772.8010	261.4529
575.0000	15.8500	16.9000	0.9379	1,772.0590	260.7311
575.0000	15.9000	16.8000	0.9464	1,773.2050	262.7438
575.0000	15.9000	16.9000	0.9408	1,772.4660	262.0220
575.0000	15.9500	16.8000	0.9494	1,773.5970	264.0350
575.0000	15.9500	16.9000	0.9438	1,772.8630	263.3132
575.0000	16.0000	16.9000	0.9467	1,772.2490	264.6047

Table 17. Input Deck That Produced the Results Shown in Table 16

```
valop5.out
Test of the output routines and Option 6
6
575.
15.9575 9.
1.225 .996 1140. 1.58
10.5 120. 475.
1500 .95
7
```

Table 18. Example of CONPRESS Input Deck for Multiple Runs

```
multi.out
This tests option 1 for latest version of CONPRESS
1
575.
9. 9.
1.225 .996 1140. 1.58
10.5 120. 475.
1200. .95
This will validate option 2 of latest version of CONPRESS
2
575.
1. 9.
1.225 .996 1140. 1.58
10.5 120. 475.
1549.07 .95
7
```

Table 19. CONPRESS Results for Input Deck Shown in Table 18

INPUT PARAMETERS

Input File: multi.in
Run Option: 1

Output File: multi.out

Gun Parameters

Cham. Vol. (L): 10.5000
Tube Diam. (mm): 120.0000
Proj. Trav. (cm): 475.0000
Proj. Mass (kg): 9.00000
Max Press. (MPa): 575.0000
Target Vel. (m/s): 1,200.0000

Propellant Parameters

Impetus (J/g): 1,140.00
Gamma (-): 1.22500
Covolume (cm^3/g): 0.99600
Density (g/cm^3): 1.58000
Input Prop. (kg): 9.00000
Target LD (g/cm^3): 0.95000

RESULTS

Ballistic Values

Velocity (m/s): 1,667.5470
Burn Out (cm): 133.8050
Cham. Vol. (L): 10.50000
Prop. Mass (kg): 9.00000
Prop. LD (g/cm^3): 0.85714
Expansion Ratio (-): 6.11631
Muzzle Exit Press (MPa): 88.31
Mass Charge/Mass Proj (c/m ratio): 1.00000
Piezometric Efficiency: 0.405

Energy Information

Prop. Energy (MJ): 45.59999
Proj. KE (MJ): 12.51320 (27.4%)
Gas KE (MJ): 4.17107 (9.1%)
Gas Internal (MJ): 28.91572 (63.4%)

INPUT PARAMETERS

Input File: multi.in
Run Option: 2

Output File: multi.out

Gun Parameters

Cham. Vol. (L): 10.5000
Tube Diam. (mm): 120.0000
Proj. Trav. (cm): 475.0000
Proj. Mass (kg): 9.00000
Max Press. (MPa): 575.0000
Target Vel. (m/s): 1,549.0700

Propellant Parameters

Impetus (J/g): 1,140.00
Gamma (-): 1.22500
Covolume (cm^3/g): 0.99600
Density (g/cm^3): 1.58000
Input Prop. (kg): 1.00000
Target LD (g/cm^3): 0.95000

RESULTS

Ballistic Values

Velocity (m/s): 1,549.0700
Burn Out (cm): 85.0453
Cham. Vol. (L): 10.50000
Prop. Mass (kg): 7.00109
Prop. LD (g/cm^3): 0.66677
Expansion Ratio (-): 6.11631
Muzzle Exit Press (MPa): 68.27
Mass Charge/Mass Proj (c/m ratio): 0.77790
Piezometric Efficiency: 0.350

Energy Information

Prop. Energy (MJ): 35.47216
Proj. KE (MJ): 10.79828 (30.4%)
Gas KE (MJ): 2.79999 (7.9%)
Gas Internal (MJ): 21.87390 (61.7%)

4. CONCLUSIONS

CONPRESS is a constant breech pressure (CBP) interior ballistic code which not only performs the basic CBP calculation but also incorporates optimization and parametric variation algorithms. In this report the derivation of the basic CBP equations is presented together with a user's manual on the use of the program. Validation of each option is also provided. It is hoped that CONPRESS will prove to be a useful tool in evaluating the potential of new propellant formulations and novel propulsion concepts.

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5. REFERENCES

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Morrison, W. F. "Novel Propulsion." Drexel University Center for Ballistic and Continuing Professional Education, Philadelphia, PA, June 1990.

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APPENDIX A:

CONPRESS SOURCE CODE LISTING:

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```
      PROGRAM CONPRESS
C***********************************************************************
C Version 2, December 1992
C
C Author:  William Oberle
C          Advanced Propulsion Technology Branch
C          Weapons Technology Directorate
C          U.S. Army Research Laboratory
C          Aberdeen Proving Ground, Maryland, 21005-5066
C          (410) 278 - 6200
C
C This program will compute performance for a constant pressure gun.
C It has several options:
C 1.  Determine the velocity, KE of projectile and location of burn out
C     given the propellant charge mass and gun geometry including
C     chamber volume.
C 2.  Determine the charge mass given the desired velocity and chamber vol.
C 3.  Determine the charge mass and chamber volume given a desired velocity
C 4.  Determine the optimal velocity give the chamber vol.; output is charge
C     mass, optimal velocity and location of burn out.
C 5.  Determine the optimal velocity with charge mass as the parameter,
C     the chamber volume is taken to be the minimal volume needed to hold
C     the propellant (subject to a specified loading density); output is
C     velocity, chamber volume, location of burn out and charge mass.
C 6.  Allows parametric runs with variations in all input parameters.
C     The calculation can be performed for any of the 5 computational
C     options.
C 7.  Flag for termination of input in multiple runs.
C
C***********************************************************************
      COMMON /XLIST/ PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP,VEL,XB1,RHO,
     1  CVF,XLD,DVEL,IOPT,VCC,XMMC,D
      COMMON /TIT/ TITLE,FILEIN,OUTFILE
      CHARACTER*20 OUTFILE,FILEIN,TITLE*60
      REAL MP,MC,KINP
      EXTERNAL ALL,FUNC
      TOL=.000001
C***********************************************************************
C************ First the input file name is determined *****************
C***********************************************************************
 805  WRITE(*,800)
 800  FORMAT(//,20X,' CONPRESS, Version 2 - December 1992',///,
     110X,' Enter the name of the input file.',
     2/,10X,' [Enter 20 to change tolerance used in search routines.]',/)
      READ(*,801) FILEIN
 801  FORMAT(A20)
C***********************************************************************
C****************** Feature to allow changing tolerance ***************
C****************** in option 4 & 5 searches **************************
C***********************************************************************
      IF (FILEIN .EQ. '20') THEN
      WRITE(*,851)TOL
 851  FORMAT(//,' The current tolerance for searches in options'
     1,/,' 4 and 5 is: ',F10.8,'.  Do you wish to enter a new value'
     2,/,' (Yes = 1, No = 2)',/)
      READ(*,*)ITOL
      IF (ITOL .EQ. 1) THEN
      WRITE(*,*)'Enter new tolerance.'
```

```
      READ(*,*)TOL
      ENDIF
      GOTO 805
      ENDIF
C***********************************************************************
C**************** Test that file exists ********************************
C***********************************************************************
      OPEN(17,FILE=FILEIN,STATUS='OLD',ERR=802)
      REWIND(17)
      GOTO 804
 802  WRITE(*,803)FILEIN
 803  FORMAT(/,' THE SPECIFIED INPUT FILE',A20,' DOES NOT EXIST!!',
     1/,' PLEASE CHECK THE FILE NAME A ENTER THE CORRECT FILE NAME.',
     2///)
      PAUSE
      GOTO 805
C***********************************************************************
C******** Program assumes that all output from a single input **********
C************** deck will be written to the same output file ***********
C***********************************************************************
 804  READ(17,801)OUTFILE
      OPEN(UNIT=18,FILE=OUTFILE)
C***********************************************************************
C******************* The input is read *********************************
C***********************************************************************
 1200 CALL INPUT(IOPT,PC,MC,MP,GAMMA,COV,F,VC,A,TRAV,RHO,DVEL,CVF,VCC
     1,XMMC,D,XLD)
C***********************************************************************
C*************** The correct option is called **************************
C***********************************************************************
      IF (IOPT .EQ. 1) GOTO 100
      IF (IOPT .EQ. 2) GOTO 200
      IF (IOPT .EQ. 3) GOTO 300
      IF (IOPT .EQ. 4) GOTO 400
      IF (IOPT .EQ. 5) GOTO 500
      IF (IOPT .EQ. 6) GOTO 600
      IF (IOPT .EQ. 7) GOTO 1000
C***********************************************************************
C*********************** OPTION 1 **************************************
C***********************************************************************
C******** The energy of the projectile is computed *********************
C***********************************************************************
 100  CALL ENERGY(PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
C******** The velocity and location of burnout is computed *************
      CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
      CALL VELO(KINP,MP,VEL)
C***********************************************************************
C************ The output for option one is written *********************
C***********************************************************************
      CALL XOUT
      GOTO 1200
C***********************************************************************
C******************** End of option 1. *********************************
C***********************************************************************
C***********************************************************************
C*********************** Option 2 **************************************
C***********************************************************************
 200  AMC=VC*RHO*.1
```

```
         BMC=VC*(1.0-CVF)*RHO
 247     CALL ENERGY(PC,AMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         AVEL=(2.0*KINP/MP)**.5-DVEL
         CALL ENERGY(PC,BMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         BVEL=(2.0*KINP/MP)**.5-DVEL
         IF((AVEL*BVEL).GT.0.0) THEN
                 WRITE(*,*)'Bisection Method will fail.'
                 WRITE(*,*)'Enter the interval to be searched.  OR'
                 WRITE(*,*)'Type Control C to terminate the program.'
                 WRITE(*,*)
                 WRITE(*,*)'Enter the endpoints on the same line.'
                 WRITE(*,*)
                 READ(*,*)AMC,BMC
                 GOTO 247
         ENDIF
         IF (ABS(AVEL).LE. 0.01) THEN
                 MC=AMC
                 CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
                 CALL VELO(KINP,MP,VEL)
                 GOTO 99
         ENDIF
         IF (ABS(BVEL).LE. 0.01) THEN
                 MC=BMC
                 CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
                 CALL VELO(KINP,MP,VEL)
                 GOTO 99
         ENDIF
 44      MC=.5*(AMC+BMC)
         CALL ENERGY(PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         CVEL=(2.0*KINP/MP)**.5-DVEL
         IF (ABS(CVEL).LE. 0.01) THEN
         CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
         CALL VELO(KINP,MP,VEL)
         GOTO 99
         ENDIF
         IF ((AVEL*CVEL).LE.0.0) THEN
                 BMC=MC
         ELSE
                 AMC=MC
         ENDIF
         GOTO 44
 99      CALL XOUT
         GOTO 1200
C*********************************************************************
C********************** End of option 2 ******************************
C*********************************************************************
C************************* Option 3 **********************************
C
C******* The initial charge mass is the minimum mass expected. ********
C******* A search will be performed to determine the endpoints ********
C******* of the interval for propellant masses starting with   ********
C******* the initial charge mass.                              ********
C*********************************************************************
 300     NTEST=1
         AMC=MC
         VC=MC/RHO
         VC=VC/(1.0-CVF)
         CALL ENERGY(PC,AMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
```

```
         AVEL=(2.0*KINP/MP)**.5-DVEL
         BMC=AMC
 111     BMC=BMC*1.2
         VC=BMC/RHO
         VC=VC/(1.0-CVF)
         CALL ENERGY(PC,BMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         BVEL=(2.0*KINP/MP)**.5-DVEL
         IF((AVEL*BVEL).GT.0.0) THEN
         NTEST=NTEST+1
         IF (NTEST .GT. 500) THEN
         WRITE(*,112)
 112     FORMAT(' A suitable right hand endpoint has not been found',
     1/,' after 500 iterations.  This corresponds to multiplying ',
     2/,' the input value of the propellant mass by 3E+36.  It ',
     3/,' appears that the desired velocity cannot be achieved in',
     4/,'the given projectile travel.  Run option 5 to determine if'
     5/,' the desired velocity can be achieved.',//)
         PAUSE
         GOTO 1000
         ENDIF
         GOTO 111
         ENDIF
C*********************************************************************
C******* The endpoints of the interval have been determined ***********
C*********************************************************************
         IF (ABS(AVEL).LE. 0.01) THEN
                       MC=AMC
                       GOTO 199
         ENDIF
         IF (ABS(BVEL).LE. 0.01) THEN
                       MC=BMC
                       GOTO 199
         ENDIF
 144     MC=.5*(AMC+BMC)
         VC=MC/RHO
         VC=VC/(1.0-CVF)
         CALL ENERGY(PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         CVEL=(2.0*KINP/MP)**.5-DVEL
         IF (ABS(CVEL).LE. 0.01) GOTO 199
         IF ((AVEL*CVEL).LE.0.0) THEN
                       BMC=MC
                       GOTO 155
         ENDIF
         AMC=MC
 155     GOTO 144
 199     VC=MC/RHO
         VC=VC/(1.0-CVF)
         CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
         CALL VELO(KINP,MP,VEL)
         CALL XOUT
         GOTO 1200
C*********************************************************************
C******************** End of option 3 ********************************
C*********************************************************************
C*********************************************************************
C************************* Option 4 **********************************
C *******************************************************************
C******* The values to bracket the charge mass are determined.  *******
```

```
C******* The max value for charge mass is the max that can be   *******
C******* held in the chamber accounting for loading density     *******
C**********************************************************************
 400      AX=0.0
C**********************************************************************
C******************** AX is left hand endpoint ************************
C*********** CX is maximum amount which can be held in chamber ********
C*********** Will determine the velocity at endpoint CX since  ********
C*********** the search routines sometimes miss the endpoint   ********
C**********************************************************************
          CX=VC*(1.0-CVF)*RHO
          CALL ENERGY(PC,CX,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
          CALL XB(PC,CX,F,MP,GAMMA,COV,VC,A,XB1)
          CALL VELO(KINP,MP,VEL)
          VELT=VEL
          KINPT=KINP
          XB1T=XB1
          MCT=CX
          BX=CX/2.0
          VEL=BRENT(AX,BX,CX,ALL,TOL,XMIN)
          VEL=-1.0*VEL
          IF (VEL .LT. VELT) THEN
          VEL=VELT
          MC=MCT
          XB1=XB1T
          MC=MCT
          ELSE
          MC=XMIN
          ENDIF
          CALL XOUT
          GOTO 1200
C**********************************************************************
C********************** End of option 4 *******************************
C**********************************************************************
C********************** Option 5 **************************************
C**********************************************************************
C************* The input chamber volume is assumed to be **************
C************* the largest acceptable volume for the run **************
C**********************************************************************
 500      AX=0.0
          CX=VC*(1.0-CVF)*RHO
C**********************************************************************
C*********** CX is maximum amount which can be held in chamber ********
C*********** Will determine the velocity at endpoint CX since  ********
C*********** the search routines sometimes miss the endpoint   ********
C**********************************************************************
          CALL ENERGY(PC,CX,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
          CALL XB(PC,CX,F,MP,GAMMA,COV,VC,A,XB1)
          CALL VELO(KINP,MP,VEL)
          VELT=VEL
          KINPT=KINP
          XB1T=XB1
          MCT=CX
          BX=CX/2.0
          VEL=BRENT(AX,BX,CX,FUNC,TOL,XMIN)
          VEL=-1.0*VEL
          IF (VEL .LT. VELT) THEN
          VEL=VELT
```

```
      MC=MCT
      XB1=XB1T
      MC=MCT
      ELSE
      MC=XMIN
      ENDIF
      VOL=MC/RHO
      VOL=VOL/(1.0-CVF)
      CALL XOUT
      GOTO 1200
C*********************************************************************
C********************** End of option 5 *******************************
C*********************************************************************
C*********************** OPTION 6 *************************************
C*********************************************************************
 600  WRITE(*,601)
 601  FORMAT(//,' This option will allow parametric runs of CONPRESS:'
     1,/,' Starting, ending and incremental values for each variable'
     2,/,' will be requested.  If the variable is not to be included'
     3,/,' in the parametric search, the input data value will be used.'
     4,/,' Output will be a file of values from the parametric run.')
      PAUSE
C*********************************************************************
C**************** CALCULATION OPTION IS DETERMIND ********************
C*********************************************************************
      WRITE(*,*)'Enter the calculation option (1 - 5).'
      READ(*,*)IOP6
      WRITE(18,607)IOP6
 607  FORMAT('1',20X,'CONPRESS VERSION 2, December 1992',
     1//,15X,' A parametric search is being performed.',
     2/,15X,' The computational option is: ',I1,//)
C*********************************************************************
C****************** Output file headers are written ******************
C*********************************************************************
      WRITE(18,699)
 699  FORMAT(/,' Max Press Prop Mass   Proj Mass  Gamma    Covol     Imp
     letus   Density   Cham Vol  Tube Diam  Travel  Load Den  Velocity
     2 Proj KE   Burn Out ')
      WRITE(18,795)
 795  FORMAT( '    (MPa)       (kg)        (kg)       (-)        (cc/g)      (J
     1/g)        (g/cc)    (Liters)     (mm)        (cm)     (g/cc)       (m/s)
     2   (MJ)         (cm)')
C*********************************************************************
      WRITE(*,*)'Vary chamber pressure? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
 602  FORMAT(/,' Enter the starting value, ending value and increment'
     1,/,' all on the same line separated by a space.'
     2,/,' Units: Pressure in MPa'
     3,/,'         Charge & Projectile Mass in kg'
     4,/,'         Covolume in cc/g'
     5,/,'         Impetus in J/g'
     6,/,'         Density in g/cc'
     7,/,'         Chamber Volume in liters'
     8,/,'         Tube Diameter in mm'
     9,/,'         Projectile Travel in cm'
     *,/,'         Loading Density in g/cc')
```

```
      READ(*,*)SPC,EPC,DPC
C************** Conversion to MKS units for program *******************
C*************** MKS NEEDED FOR LOOP, 1E7 ARE TOO BIG *****************
C********** Will convert to cgs at the loop ***************************
      ELSE
      SPC=PC/1.E7
      EPC=PC/1.E7
      DPC=PC/1.E7
      ENDIF
C*********************************************************************
      IF (IOP6 .NE. 1) THEN
      SMC=MC
      EMC=MC
      DMC=MC
   GOTO 1487
      ENDIF
      WRITE(*,*)'Vary charge mass? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SMC,EMC,DMC
C************** Conversion to grams for program **********************
      SMC=SMC*1000.
      EMC=EMC*1000.
      DMC=DMC*1000.
      ELSE
      SMC=MC
      EMC=MC
      DMC=MC
      ENDIF
C*********************************************************************
 1487 WRITE(*,*)'Vary projectile mass? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SMP,EMP,DMP
C************** Conversion to grams for program **********************
      SMP=SMP*1000.
      EMP=EMP*1000.
      DMP=DMP*1000.
      ELSE
      SMP=MP
      EMP=MP
      DMP=MP
      ENDIF
C*********************************************************************
      WRITE(*,*)'Vary gamma? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SGAM,EGAM,DGAM
      ELSE
      SGAM=GAMMA
      EGAM=GAMMA
      DGAM=GAMMA
      ENDIF
C*********************************************************************
      WRITE(*,*)'Vary covolume? (Yes = 1, No = 2)'
```

```
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SCOV,ECOV,DCOV
      ELSE
      SCOV=COV
      ECOV=COV
      DCOV=COV
      ENDIF
C***********************************************************************
      WRITE(*,*)'Vary propellant impetus? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SF,EF,DF
C************** Conversion to cgs units for program ******************
      SF=SF*1.E+07
      EF=EF*1.E+07
      DF=DF*1.E+07
      ELSE
      SF=F
      EF=F
      DF=F
      ENDIF
C***********************************************************************
      WRITE(*,*)'Vary propellant density? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SRHO,ERHO,DRHO
      ELSE
      SRHO=RHO
      ERHO=RHO
      DRHO=RHO
      ENDIF
C***********************************************************************
      IF ((IOP6 .EQ. 3) .OR. (IOP6 .EQ. 5)) THEN
      SVC=VC
      EVC=VC
      DVC=VC
    GOTO 9842
      ENDIF
      WRITE(*,*)'Vary chamber volume? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SVC,EVC,DVC
C*************** Conversion to cc for program **************************
      SVC=SVC*1000.
      EVC=EVC*1000.
      DVC=DVC*1000.
      ELSE
      SVC=VC
      EVC=VC
      DVC=VC
      ENDIF
C***********************************************************************
 9842 WRITE(*,*)'Vary tube diameter? (Yes = 1, No = 2)'
```

```
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SD,ED,DD
C************** Conversion to cm for program ***************************
      SD=SD/10.
      ED=ED/10.
      DD=DD/10.
      ELSE
      SD=D
      ED=D
      DD=D
      ENDIF
C**********************************************************************
      WRITE(*,*)'Vary projectile travel? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)STRAV,ETRAV,DTRAV
      ELSE
      STRAV=TRAV
      ETRAV=TRAV
      DTRAV=TRAV
      ENDIF
C**********************************************************************
      IF (IOP6 .EQ. 1) THEN
      SXLD=XLD
      EXLD=XLD
      DXLD=XLD
      GOTO 3876
      ENDIF
      WRITE(*,*)'Vary loading density? (Yes = 1, No = 2)'
      READ(*,*)ITEST
      IF (ITEST .EQ. 1) THEN
      WRITE(*,602)
      READ(*,*)SXLD,EXLD,DXLD
      ELSE
      SXLD=XLD
      EXLD=XLD
      DXLD=XLD
      ENDIF
C**********************************************************************
 3876 DO 650 PC1=SPC,EPC,DPC
     PC=PC1*1.E7
      DO 650 MC1=SMC,EMC,DMC
      DO 650 MP=SMP,EMP,DMP
      DO 650 GAMMA=SGAM,EGAM,DGAM
      DO 650 COV=SCOV,ECOV,DCOV
      DO 650 F=SF,EF,DF
      DO 650 RHO=SRHO,ERHO,DRHO
      DO 650 VC1=SVC,EVC,DVC
      DO 650 D=SD,ED,DD
      A=3.14159265359*(D/2.0)**2.0
      DO 650 TRAV=STRAV,ETRAV,DTRAV
      DO 650 XLD=SXLD,EXLD,DXLD
      CVF=1.-(XLD/RHO)
C**********************************************************************
C***************** OPTION 1 CALCULATION ********************************
```

```
C************************************************************************
          IF (IOP6 .EQ. 1) THEN
          MC=MC1
          VC=VC1
          CALL ENERGY(PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
          CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
          CALL VELO(KINP,MP,VEL)
       GOTO 631
          ENDIF
C************************************************************************
C***************** OPTION 2 CALCULATION *********************************
C************************************************************************
          IF (IOP6 .EQ. 2) THEN
          VC=VC1
          AMC=VC*RHO*.1
          BMC=VC*(1.0-CVF)*RHO
 2247     CALL ENERGY(PC,AMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
          AVEL=(2.0*KINP/MP)**.5-DVEL
          CALL ENERGY(PC,BMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
          BVEL=(2.0*KINP/MP)**.5-DVEL
          IF((AVEL*BVEL).GT.0.0) THEN
                    WRITE(*,*)'Bisection Method will fail.'
                    WRITE(*,*)'Enter the interval to be searched.  OR'
                    WRITE(*,*)'Type Control C to terminate the program.'
                    WRITE(*,*)
                    WRITE(*,*)'Enter the endpoints on the same line.'
                    WRITE(*,*)
                    READ(*,*)AMC,BMC
                    GOTO 2247
          ENDIF
          IF (ABS(AVEL).LE. 0.01) THEN
                    MC=AMC
                    CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
                    CALL VELO(KINP,MP,VEL)
                    GOTO 631
          ENDIF
          IF (ABS(BVEL).LE. 0.01) THEN
                    MC=BMC
                    CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
                    CALL VELO(KINP,MP,VEL)
                    GOTO 631
          ENDIF
 244      MC=.5*(AMC+BMC)
          CALL ENERGY(PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
          CVEL=(2.0*KINP/MP)**.5-DVEL
          IF (ABS(CVEL).LE. 0.01) THEN
          CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
          CALL VELO(KINP,MP,VEL)
          GOTO 631
          ENDIF
          IF ((AVEL*CVEL).LE.0.0) THEN
                    BMC=MC
          ELSE
                    AMC=MC
          ENDIF
          GOTO 244
          ENDIF
C************************************************************************
```

```
C***************** OPTION 3 CALCULATION ********************************
C**********************************************************************
         IF (IOP6 .EQ. 3) THEN
         MC=MC1
         NTEST=1
         AMC=MC
         VC=MC/RHO
         VC=VC/(1.0-CVF)
         CALL ENERGY(PC,AMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         AVEL=(2.0*KINP/MP)**.5-DVEL
         BMC=AMC
 3111    BMC=BMC*1.2
         VC=BMC/RHO
         VC=VC/(1.0-CVF)
         CALL ENERGY(PC,BMC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         BVEL=(2.0*KINP/MP)**.5-DVEL
         IF((AVEL*BVEL).GT.0.0) THEN
         NTEST=NTEST+1
         IF (NTEST .GT. 500) THEN
         WRITE(*,3112)
 3112    FORMAT(' A suitable right hand endpoint has not been found',
     1/,' after 500 iterations.  This corresponds to multiplying ',
     2/,' the input value of the propellant mass by 3E+36.  It ',
     3/,' appears that the desired velocity cannot be achieved in',
     4/,'the given projectile travel.  Run option 5 to determine if'
     5/,' the desired velocity can be achieved.',//)
         PAUSE
         GOTO 1000
         ENDIF
         GOTO 3111
         ENDIF
C**********************************************************************
C******* The endpoints of the interval have been determined ***********
C**********************************************************************
         IF (ABS(AVEL).LE. 0.01) THEN
                      MC=AMC
                      GOTO 3199
         ENDIF
         IF (ABS(BVEL).LE. 0.01) THEN
                      MC=BMC
                      GOTO 3199
         ENDIF
 3144    MC=.5*(AMC+BMC)
         VC=MC/RHO
         VC=VC/(1.0-CVF)
         CALL ENERGY(PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
         CVEL=(2.0*KINP/MP)**.5-DVEL
         IF (ABS(CVEL).LE. 0.01) GOTO 3199
         IF ((AVEL*CVEL).LE.0.0) THEN
                      BMC=MC
                      GOTO 3155
         ENDIF
         AMC=MC
 3155    GOTO 3144
 3199    VC=MC/RHO
         VC=VC/(1.0-CVF)
         CALL XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
         CALL VELO(KINP,MP,VEL)
```

```
      GOTO 631
      ENDIF
C*********************************************************************
C***************** OPTION 4 CALCULATION ******************************
C*********************************************************************
      IF (IOP6 .EQ. 4) THEN
      VC=VC1
      AX=0.0
C*********************************************************************
C******************** AX is left hand endpoint ***********************
C*********** CX is maximum amount which can be held in chamber ********
C*********** Will determine the velocity at endpoint CX since  ********
C*********** the search routines sometimes miss the endpoint   ********
C*********************************************************************
      CX=VC*(1.0-CVF)*RHO
      CALL ENERGY(PC,CX,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
      CALL XB(PC,CX,F,MP,GAMMA,COV,VC,A,XB1)
      CALL VELO(KINP,MP,VEL)
      VELT=VEL
      KINPT=KINP
      XB1T=XB1
      MCT=CX
      BX=CX/2.0
      VEL=BRENT(AX,BX,CX,ALL,TOL,XMIN)
      VEL=-1.0*VEL
      IF (VEL .LT. VELT) THEN
      VEL=VELT
      MC=MCT
      XB1=XB1T
      MC=MCT
      ELSE
      MC=XMIN
      ENDIF
      GOTO 631
      ENDIF
C*********************************************************************
C***************** OPTION 5 CALCULATION ******************************
C*********************************************************************
      IF (IOP6 .EQ. 5) THEN
      VC=VC1
      AX=0.0
      CX=VC*(1.0-CVF)*RHO
C*********************************************************************
C*********** CX is maximum amount which can be held in chamber ********
C*********** Will determine the velocity at endpoint CX since  ********
C*********** the search routines sometimes miss the endpoint   ********
C*********************************************************************
      CALL ENERGY(PC,CX,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
      CALL XB(PC,CX,F,MP,GAMMA,COV,VC,A,XB1)
      CALL VELO(KINP,MP,VEL)
      VELT=VEL
      KINPT=KINP
      XB1T=XB1
      MCT=CX
      BX=CX/2.0
      VEL=BRENT(AX,BX,CX,FUNC,TOL,XMIN)
      VEL=-1.0*VEL
      IF (VEL .LT. VELT) THEN
```

```
      VEL=VELT
      MC=MCT
      XB1=XB1T
      MC=MCT
      ELSE
      MC=XMIN
      ENDIF
      VOL=MC/RHO
      VOL=VOL/(1.0-CVF)
      GOTO 631
      ENDIF
C****************** CONVERSION FOR PRINTOUT ****************************
 631  A1=PC*1E-7
      A2=MC/1000.
      A3=MP/1000.
      A4=GAMMA
      A5=COV
      A6=F*1.E-7
      A7=RHO
      A8=VC/1000.
      A9=D*10.
      A10=TRAV
      A11=A2/A8
      A12=VEL/100.
      A13=KINP*1.E-7*1.E-6
      A14=XB1
C**********************************************************************
C********************** Values written to file *************************
C**********************************************************************
      WRITE(18,651)A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14
 651  FORMAT(14F10.4)
 650  CONTINUE
    GOTO 1200
C**********************************************************************
C********************** END OF OPTION 6 *******************************
C**********************************************************************
 1000 CLOSE(UNIT=17)
      CLOSE(UNIT=18)
      END
C**********************************************************************
C************************** Input Subroutine ***************************
C**********************************************************************
      SUBROUTINE INPUT(IOPT,PC,MC,MP,GAMMA,COV,F,VC,A,TRAV,RHO,DVEL,
     1           CVF,VCC,XMMC,D,XLD)
C**********************************************************************
C********************** Information on input parameters ****************
C**********************************************************************
C                    INPUT PARAMETERS REQUIRED
C
C                         IOPT     -- Program option flag
C                         PC       -- Pressure in MPa
C                         MC,XMMC  -- Charge mass in kg
C                         MP       -- Projectile mass in kg
C                         GAMMA    -- Ratio of specific heats
C                         COV      -- Propellant covolume in cc/g
C                         F        -- Propellant impetus in J/g
C                         RHO      -- Propellant density in g/cc
C                         VC,VCC   -- Chamber volume without propellant in L
```

```
C                        D        -- Gun tube diameter (mm)
C                        TRAV     -- Projectile travel in cm
C                        DVEL     -- Desired velocity (m/s)
C                        XLD      -- Desired propellant loading density (g/cc)
C
C                   COMPUTED VALUES
C
C                        A        -- Bore cross-sectional area cm^2
C                        CVF      -- Chamber void fraction; fraction of chamber
C                          which cannot contain propellant
C***********************************************************************
          COMMON /TIT/ TITLE,FILEIN,OUTFILE
          CHARACTER*20 TITLE*60,FILEIN,OUTFILE
          REAL MC,MP
C***********************************************************************
          READ(17,800,END=900)TITLE
 800      FORMAT(A60)
          IF (TITLE .EQ. '7') GOTO 905
          READ(17,*,END=900)IOPT
          IF (IOPT .EQ. 7) GOTO 905
          READ(17,*,END=900)PC
          READ(17,*,END=900)MC,MP
          READ(17,*,END=900)GAMMA,COV,F,RHO
          READ(17,*,END=900)VC,D,TRAV
          READ(17,*,END=900)DVEL,XLD
C***********************************************************************
C******* Conversion of all quantities to cgs system of units **********
C***********************************************************************
          PC=PC*1.0E+07
          MC=MC*1000.0
          XMMC=MC
          MP=MP*1000.0
          F=F*1.0E+07
          VC=VC*1000.
          VCC=VC
          D=D/10.
          A=3.14159265359*(D/2.0)**2.0
          DVEL=DVEL*100.
C***********************************************************************
C***************** Compute chamber void fraction ***********************
C***********************************************************************
          CVF=1.-(XLD/RHO)
          GOTO 901
 900      WRITE(18,902)
 902      FORMAT(//,' Unexpected end of file has occurred.',
     1/,' Program Terminated')
 905      CLOSE(UNIT=17)
          CLOSE(UNIT=18)
          STOP
 901      RETURN
          END
C***********************************************************************
C********************** Subroutine Energy ******************************
C***********************************************************************
          SUBROUTINE ENERGY(PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP)
          REAL MC,MP,KINP
          V1F=VC-COV*MC
          VMF=VC+A*TRAV-COV*MC
```

```
      CON1=1+MC/(2.0*MP)
      CON2=1+MC/(3.0*MP)
      CON3=GAMMA-1.0
      VBF=MC*F*CON1/(GAMMA*CON2*PC)+CON3*V1F/GAMMA
      CON4=(VBF/VMF)**GAMMA
      KINP=PC/CON1*(GAMMA/CON3*VBF-V1F-VMF*CON4/CON3)
      RETURN
      END
C**********************************************************************
C********************* Subroutine XB **********************************
C**********************************************************************
      SUBROUTINE XB(PC,MC,F,MP,GAMMA,COV,VC,A,XB1)
      REAL MC,MP
      V1F=VC-COV*MC
      CON1=1+MC/(2.0*MP)
      CON2=1+MC/(3.0*MP)
      CON3=GAMMA-1.0
      VBF=MC*F*CON1/(GAMMA*CON2*PC)+CON3*V1F/GAMMA
      VBF1=VBF+COV*MC-VC
      XB1=VBF1/A
      RETURN
      END
C**********************************************************************
C********************* Subroutine VELO ********************************
C**********************************************************************
      SUBROUTINE VELO(KINP,MP,VEL)
      REAL MP,KINP
      VEL=(2.0*KINP/MP)**.5
      RETURN
      END
C**********************************************************************
C******** The function all is used in the subroutine BRENT ************
C**********************************************************************
      FUNCTION ALL(XX)
      COMMON /XLIST/ PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP,VEL,XB1,RHO,
     1  CVF,XLD,DVEL,IOPT,VCC,XMMC,D
      REAL MC,MP,KINP
      V1F=VC-COV*XX
      VMF=VC+A*TRAV-COV*XX
      CON1=1+XX/(2.0*MP)
      CON2=1+XX/(3.0*MP)
      CON3=GAMMA-1.0
      VBF=XX*F*CON1/(GAMMA*CON2*PC)+CON3*V1F/GAMMA
      CON4=(VBF/VMF)**GAMMA
      KINP=PC/CON1*(GAMMA/CON3*VBF-V1F-VMF*CON4/CON3)
      VBF1=VBF+COV*XX-VC
      XB1=VBF1/A
      VEL=(2.0*KINP/MP)**.5
      ALL=-1.0*VEL
      RETURN
      END
C**********************************************************************
C********************* FUNCTION BRENT *********************************
C**********************************************************************
      FUNCTION BRENT(AX,BX,CX,F,TOL,XMIN)
      EXTERNAL F
      PARAMETER (ITMAX=100,CGOLD=.3819660,ZEPS=1.0E-10)
      A=MIN(AX,CX)
```

```
      B=MAX(AX,CX)
      V=BX
      W=V
      X=V
      E=0.
      FX=F(X)
      FV=FX
      FW=FX
      DO 11 ITER=1,ITMAX
      XM=0.5*(A+B)
      TOL1=TOL*ABS(X)+ZEPS
      TOL2=2.*TOL1
      IF(ABS(X-XM).LE.(TOL2-.5*(B-A))) GOTO 3
      IF(ABS(E).GT.TOL1) THEN
      R=(X-W)*(FX-FV)
      Q=(X-V)*(FX-FW)
      P=(X-V)*Q-(X-W)*R
      Q=2.*(Q-R)
      IF(Q.GT.0.) P=-P
      Q=ABS(Q)
      ETEMP=E
      E=D
      IF(ABS(P).GE.ABS(.5*Q*ETEMP).OR.P.LE.Q*(A-X).OR.
     * P.GE.Q*(B-X)) GOTO 1
      D=P/Q
      U=X+D
      IF(U-A.LT.TOL2 .OR. B-U.LT.TOL2) D=SIGN(TOL1,XM-X)
      GOTO 2
      ENDIF
1     IF(X.GE.XM) THEN
      E=A-X
      ELSE
      E=B-X
      ENDIF
      D=CGOLD*E
2     IF(ABS(D).GE.TOL1) THEN
      U=X+D
      ELSE
      U=X+SIGN(TOL1,D)
      ENDIF
      FU=F(U)
      IF(FU.LE.FX) THEN
      IF(U.GE.X) THEN
      A=X
      ELSE
      B=X
      ENDIF
      V=W
      FV=FW
      W=X
      FW=FX
      X=U
      FX=FU
      ELSE
      IF(U.LT.X) THEN
      A=U
      ELSE
      B=U
```

```
      ENDIF
      IF(FU.LE.FW .OR. W.EQ.X) THEN
      V=W
      FV=FW
      W=U
      FW=FU
      ELSE IF(FU.LE.FV .OR. V.EQ.X .OR. V.EQ.W) THEN
      V=U
      FV=FU
      ENDIF
      ENDIF
 11   CONTINUE
      PAUSE 'Brent exceed maximum iterations.'
 3    XMIN=X
      BRENT=FX
      RETURN
      END
C**********************************************************************
C**** The function all is used in the subroutine BRENT in option 5. ***
C**********************************************************************
      FUNCTION FUNC(P)
      COMMON /XLIST/ PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP,VEL,XB1,RHO,
     1  CVF,XLD,DVEL,IOPT,VCC,XMMC,D
      REAL MC,MP,KINP
      MC=P
      VC=MC/RHO
      VC=VC/(1.0-CVF)
      V1F=VC-COV*MC
      VMF=VC+A*TRAV-COV*MC
      CON1=1+MC/(2.0*MP)
      CON2=1+MC/(3.0*MP)
      CON3=GAMMA-1.0
      VBF=MC*F*CON1/(GAMMA*CON2*PC)+CON3*V1F/GAMMA
      CON4=(VBF/VMF)**GAMMA
      KINP=PC/CON1*(GAMMA/CON3*VBF-V1F-VMF*CON4/CON3)
      VBF1=VBF+COV*MC-VC
      XB1=VBF1/A
      VEL=(2.0*KINP/MP)**.5
      FUNC=-1.0*VEL
      RETURN
      END
C**********************************************************************
C********************** OUTPUT SUBROUTINE *****************************
C**********************************************************************
      SUBROUTINE XOUT
      COMMON /XLIST/ PC,MC,F,MP,GAMMA,COV,VC,A,TRAV,KINP,VEL,XB1,RHO,
     1  CVF,XLD,DVEL,IOPT,VCC,XMMC,D
      COMMON /TIT/ TITLE,FILEIN,OUTFILE
      CHARACTER*20 TITLE*60,FILEIN,OUTFILE
      REAL MP,MC,KINP
C**********************************************************************
C**************** First Echo of Input *********************************
C**********************************************************************
      WRITE(18,799)
 799  FORMAT(//,T20,' CONPRESS PROGRAM (Version 2) RESULTS')
      WRITE(18,800)TITLE
 800  FORMAT(//,' Title: ',A60,//,27X,' INPUT PARAMETERS',/)
      WRITE(18,801)FILEIN,OUTFILE,IOPT
```

```
801       FORMAT(' Input File: ',A20,4X,'Output File: ',A20,
    1/,' Run Option: ',I2,/)
          WRITE(18,802)
802       FORMAT(' Gun Parameters',25X,'Propellant Parameters',/,
    1' --- ----------',25X,'---------- ----------',/)
          XVC=VCC/1.E3
          XF=F/1.E7
          WRITE(18,803)XVC,XF
803       FORMAT(' Cham. Vol. (L)',T23,':',F10.4,T35,'Impetus (J/g)',
    1T59,':',F10.2)
          XD=D*10.
          WRITE(18,804)XD,GAMMA
804       FORMAT(' Tube Diam. (mm)',T23,':',F10.4,T35,'Gamma (-)',
    1T59,':',F10.5)
          WRITE(18,805)TRAV,COV
805       FORMAT(' Proj. Trav. (cm)',T23,':',F10.4,T35,'Covolume (cc/g)',
    1T59,':',F10.5)
      XMP=MP/1000.
          WRITE(18,806)XMP,RHO
806       FORMAT(' Proj. Mass (kg)',T23,':',F10.5,T35,'Density (g/cc)',
    1T59,':',F10.5)
          XPC=PC/1.E7
          XMMC=XMMC/1000.
          WRITE(18,807)XPC,XMMC
807       FORMAT(' Max Press. (MPa)',T23,':',F10.4,T35,'Input Prop. (kg)',
    1T59,':',F10.5)
          XDVEL=DVEL/100.
          WRITE(18,808)XDVEL,XLD
808       FORMAT(' Target Vel.(m/s)',T23,':',F10.4,T35,'Target LD (g/cc)'
    1T59,':',F10.5,//,30X,'RESULTS',/)
          WRITE(18,809)
809       FORMAT(' Ballistic Values',23X,'Energy Infomation',/,
    1' --------- ------',23X,'------ -----------',/)
          XV=VEL/100.
          XMC=MC/1000.
          XPE=F/1.E7*MC/(GAMMA-1.)/1.E6
          WRITE(18,810)XV,XPE
810       FORMAT(' Velocity (m/s)',T23,':',F10.4,T35,'Prop. Energy (MJ)',
    1T59,':',F10.5)
          XVC=VC/1000.
          XKINP=KINP*1.0E-07
          XPKE=XKINP/1.E6
          PER=XPKE/XPE*100.
          WRITE(18,811)XB1,XPKE,PER
811       FORMAT(' Burn Out (cm)',T23,':',F10.4,T35,'Proj. KE (MJ)',
    1T59,':',F10.5,' (',F5.1,'%)')
          XGKE=(1./3.)*MC/MP*XPKE
          PER=XGKE/XPE*100.
          WRITE(18,812)XVC,XGKE,PER
812       FORMAT(' Cham. Vol. (L)',T23,':',F10.5,T35,'Gas. KE (MJ)',
    1T59,':',F10.5,' (',F5.1,'%)')
          XGI=XPE-XPKE-XGKE
          PER=XGI/XPE*100.
          WRITE(18,813)XMC,XGI,PER
813       FORMAT(' Prop. Mass (kg)',T23,':',F10.5,T35,'Gas Internal (MJ)',
    1T59,':',F10.5,' (',F5.1,'%)')
          XLLD=MC/VC
          WRITE(18,814)XLLD
```

```
814       FORMAT(' Prop. LD (g/cc)',T23,':',F10.5)
          ER=(VC+A*TRAV)/VC
          WRITE(18,815)ER
815       FORMAT(//,' Expansion Ratio (-)',T23,':',F10.5)
          XXV=(VC+A*TRAV)/1.E6-COV*XMC/1000.
          XGI=XGI*1.E6
          PMEAN=XGI*(GAMMA-1.)/XXV
          PBASE=PMEAN/(1.+1./3.*XMC/XMP)
          PBASE=PBASE/1.E6
          WRITE(18,816)PBASE
816       FORMAT(' Muzzle Exit Press (MPa):',F10.2)
          WRITE(18,817)XMC/XMP
817       FORMAT(' Mass Charge/Mass Proj (c/m ratio): ',F10.5)
          PE=XKINP/XPC/TRAV/A
          WRITE(18,818)PE
818       FORMAT(' Piezometric Efficiency: ',F10.3)
          RETURN
          END
```

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